



TRANSFORMING FOOD ANALYSIS AND CONTROL:

NON-DESTRUCTIVE TECHNOLOGIES AND INNOVATIONS

K. Prasad, S. Shekhar, M. K. Paswan and R. Ahuja



Advancing Food Quality, Safety and Sustainability with
Smart, Innovative and Non-Destructive Technologies



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Smart Vibration Sensing and Machine Learning for Non-Destructive Estimation of Tender Coconut Water Volume

Abhinav Dubey , Ruchika Zalpouri, Chandni, Shrikrishna Nishani, and Sandeep Mann 

Abstract. Tender coconut quality is primarily determined by internal attributes such as water volume and physiological maturity, which are difficult to assess using conventional destructive or subjective methods. Acoustic non-destructive techniques have emerged as effective tools for evaluating these attributes by exploiting the relationship between mechanical vibration response and internal mass stiffness characteristics. This chapter reviews the principles, instrumentation, and signal-processing approaches of acoustic resonance, mechanical vibration, ultrasonic, and acoustic emission methods specifically applied to tender coconut. Recent advances integrating machine learning models for water volume prediction are discussed, highlighting their relevance for large-scale grading and quality assurance in the coconut industry.

Keywords: Non-destructive evaluation, vibration, sensing, tender coconut

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1. Introduction

Tender coconut (*Cocos nucifera* L.) holds a unique position in the global horticultural and beverage markets due to its high nutritional value, refreshing taste, and rising consumer demand for natural, minimally processed drinks. Unlike mature coconuts, tender coconuts are harvested at an early physiological stage (typically 6–7 months after flowering), when the liquid endosperm (coconut water) is at its maximum volume and optimal sensory quality (Naik et al., 2022). At this stage, the kernel is soft and gelatinous, and the shell has not yet fully hardened. These attributes make tender coconut highly desirable but also extremely challenging to grade and standardise using conventional quality evaluation methods (Shi et al., 2025). Traditionally, tender coconut quality has been judged using empirical and experience-based practices such as tapping the shell and listening to the sound, visual inspection of husk colour, weight-based estimation, or flotation tests (Dubey et al., 2025). While these approaches are rapid and inexpensive, they are inherently subjective, inconsistent, and poorly correlated with internal attributes such as water volume, kernel thickness, and physiological maturity. Destructive methods, including cutting the nut to measure water volume or biochemical analysis, provide accurate information but result in complete product loss and are therefore unsuitable for commercial grading, especially when 100% inspection is desired (Wang et al., 2026).

In this context, non-destructive testing (NDT) techniques have gained increasing attention as tools capable of evaluating internal quality while preserving the integrity of the fruit. Among various NDT approaches, acoustic-based non-destructive methods have emerged as particularly promising for tender coconut due to their simplicity, low cost, rapid measurement capability, and a strong physical link between acoustic response and the mechanical–structural properties of biological tissues (Dubey et al., 2025). Acoustic methods are fundamentally rooted in the interaction between mechanical vibrations and the mass–stiffness characteristics of the coconut shell–water–kernel system. Even subtle changes in water volume or tissue firmness can significantly alter the acoustic signature generated when the fruit is excited (Nair U. K et al., 2024; Syahansyah et al., 2022).

This chapter presents a focused synthesis of acoustic-based non-destructive techniques for the quality assessment of tender coconut. It critically examines

Table 1. Overview of acoustic non-destructive techniques for tender coconut quality assessment.

Technique	Principle	Key Parameters	Advantages	Limitations
Acoustic Resonance	Natural vibration response to impact	Dominant frequency, damping	Simple, low-cost, fast	Sensitive to noise
Mechanical Vibration + ML	Frequency attenuation modelling	Spectral features	High accuracy	Requires training data
Ultrasonic Analysis	Wave propagation in liquid/tissue	Velocity, attenuation	Sensitive to composition	Limited penetration
Acoustic Emission	Stress-induced elastic waves	Event rate, amplitude	Structural insight	Complex setup

8. Conclusion

Acoustic non-destructive methods provide a scientifically grounded, practical, and scalable solution for assessing tender coconut quality. By exploiting the intrinsic relationship between acoustic response and internal physical properties, these techniques enable rapid estimation of water volume and maturity without damaging the fruit. The integration of advanced signal processing and machine learning has significantly enhanced prediction accuracy, moving acoustic methods beyond empirical tapping toward quantitative, automated grading systems. Continued advances in sensor design, embedded intelligence, and field validation are expected to accelerate commercial adoption, particularly in major coconut-producing countries such as India.

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